Optical Fiber Communication System:-

References:-

1. Fiber optic communication. By Joseph C Palais
2. Fiber optic communication. By D.C Agarwal
3. Optical fiber communication. By Gerd keiser
4. Optical fiber communication and its application. By S.C Gupta
5. Manual on antenna.

Introduction: There are many advantages of optical fiber communication system (OFC) over the conventional copper cable. Some of them are :

1. Broad bandwidth
2. Immunity electromagnetic interference.
3. Low attenuation loss over long distances.
4. Signal security and no cross talk.
5. Light weight and small diameter cables.
6. Electrical insulator.
7. Low cost for long distance communication.
8. Ruggedness and flexibility.

History and evolution:-

- One of the earliest known optical transmission was the use of fire signal by geeks in 8th century B.C. for sending alarm, calls for help or announcements of certain even.
- The main drawback with this communication system using light transmission was that it involved line of sight communication. Here the optical signal is unguided and it is also transmitted through atmosphere where it is subjected to the attenuation and even distortion when weather condition are fair. Therefore a better optical wave communication system would certainly need a light guide to help preserve the signal and so increase the reliability and distance of transmission.
- In 1910 the practical wave guide was used. This guide was a solid cylinder capable of guiding a wide range of EM waves including the visible light. At the same time another light guide developed consisted of a hollow tube with a highly reflecting matter coating on its inner surface.
- Experiments on class fibers packed into bundles where carried out in 1930 to make them work as light guide. Although this design improved the transmission efficiency, handling of fibers, reduced cross talk between fibers in bundles, signal losses restricted optical fiber to applications of few meters at the most.
- Nippon Glass Company of Japan was able to develop graded index fibers in 1968. This fibers at a loss of less then 20Db per km.
- The development of laser in 1960 was a landmark for OFC using coherent light signal. Though initial laser has poor life times and were required to work at low temperature, todays laser have projected life time of upto 10 years at room temperature and above.

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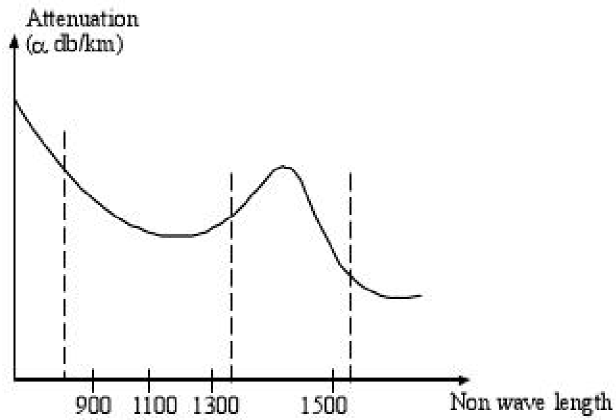
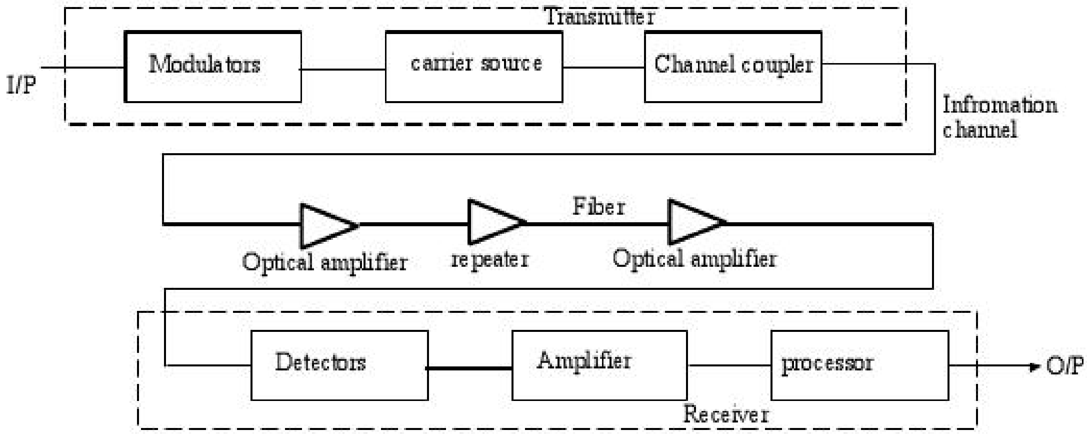


Fig: optical fiber system operating range.
B= transmission bit rate
L = repeater spacing.

- The 1G links operated at around at 850 nm, which was low transmission window of early silica fibers. These links used existing gaAs based optical sources, silicon photo detector and multimode fibers. Intermodel depression and fiber loss at this wave length limited the capacity of the system. Intercity application ranged from 45 to 140 mbps with repeater spacing of around 10 km.
- The development of optical sources and photo detectors capable of operating at 1300 nm allowed a shift in the transmission wavelength from 800 to 1300 nm. This resulted in substantial increase in the repeater less transmission distance for long haul telephone trunks.
- In 1984 single mode fiber were extensively used which have significantly larger bandwidth bit rates range from 155 to 622 Mbps over specing of repeater at 40 km.
- At 1550 nm there was much larger signal dispersion but manufactures overcome this problem by creating the so called dispersion shifter fiber. These links carray traffic at around 2.5 Gbps over 90 km repeater less distances.
- By 1996 advances in high quality leasers and receiver allowed single wave length transmission rate of around 10 Gbps.
- Finally starting in the mid 1990 a combination of EDFA (Erbium duct fibers amplifiers) and WDM (Wave length division multiplexing) was used to bushed fiber capacity to even higher level and to increase the transmission distance.

Optical fiber communication system:-



The generalize OFC system is described below:

1. The message origin may take several physical forms. Quite often it is the transducer that converts the non electrical message into an electrical signal. Common examples include microphones for converting sound waves into currents and video camera for converting images into currents.
2. It has mainly two parts
   a. It converts the electrical message signal into proper format i.e analog or digital
   b. It improves the signal into the wave generated by the carrier sources.
3. The carrier sources:- The carrier sources generates the wave on which the information is transmitted. This wave is called the carrier. For OFC system LD (laser diode) or LED are used which are also called optic oscillator. Ideally they provide stable single frequency wave with sufficient power for long distance communication.
4. Information channel: It refers to the path between transmitter and receiver. In OFC system, a glass or plastic fiber is the channel. The power into the information channel is fed through the channel coupler. Desirable characteristics of the information channel include low attenuation and large light acceptance cone angle for transmission over long path lengths.

Optical amplifiers bust the power level of weak signals. Amplifiers are needed in very long links to provide sufficient power to the receiver.

Repeaters can be used only for digital system. They convert weak and distorted optical signals to electrical signals and then regenerate original digital pulse train for further transmission. In long systems numerous amplifiers and repeaters may be used.

5. Detector or photo detector: The information must now be taken off the carrier wave. In OFC system the optic wave is converted into an electric current by a photo detector. The current developed by this detector is proportional to the power of the incident optic wave.

6. Signal processing:- For analog transmission the signal processor includes the amplification and filter of the signal. For a digital system, the processor includes decision circuits in addition to amplifiers and filters.

7. Message output:- Finally the message is presented to a person who either hears or views the information or it may directly usable in electrical form.

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Application of OFC:

Fiber optics has tremendous application in every part of life and several such applications have already been implemented in practice to varying degrees. Some of detailed applications are as follows:

1. **Telecommunication/ Telephone applications:-** The various applications of fiber optics in the telecommunication area in general could be in voice telephone, video phones, various new services, messages services and data networks all transmitted over the common carrier link.
2. **Military application:-** These include communication, command and control links on ships and aircraft, data links for satellite earth stations and under sea system for which EMI effect, weight and size, signal leakage and attenuation plays a major role. OFC systems meet this requirement.
3. **Space application:-** Optical fibers offer the following significant advantages for space environment ;namely high bandwidth(greater than 1 Ghz as compared to 1 Mhz for twisted pair), noise immunity, inherent radiation, reduce weight (90% weight savings over conventional wire system), low bit error rate, size and volume reduction, EMI immunity and lower cost.
4. **Sensor application:-** A fiber optic sensor consists of a length of a fiber that modulates the light passing though it when exposed to the changing environment one wants to sense. The physical effects exposed to the environment lead to changes in frequency, intensity and polarization of light and thus cause variation in the resultant optical signal.
5. **Under sea transmission cables:-** Coaxial under sea cable systems have been used as one of the major transmission systems in international telecommunication networks over the past 25 years. But this system has nearly reached a limit in its ability to increase the capacities. Therefore optical fiber under sea cable system are considered to be very promising technology to over come these barriers.
6. **Broad band applications:** Application that are primilarly broadband services include broadcast tv, cable tv (CTV, community antenna television) , remote monitory, and surveillance system.
7. **Computer application:-** Fiber system are particularly suited for transmission of digital data, such as that generated by the computers. Interconnections can be made between CPU and memories, CPU and peripherals and between CPUs.
8. **OFC for electric power companies:-** Electric power companies are progressively installing the OFC system for power system protections, supervision and control, measurements etc.
9. **Miscellaneous:-** These include biomedical applications. General home appliances application. Small office building and so on.

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Light wave fundamental:

Electromagnetic wave:-

Light consists of an electric field and a rates of the order of 10^{14} hz. These fields travels in wavelike fashion at very high speeds. At any fixed location, the field amplitude varies at the optic frequency the amplitude repeats itself in space at fixed time, offer a distance known as λ , known as wavelength. Its reciprocal 1/λ is the wave number.

The electric field for the wave can be written as,

$E = E_o \cos (wt- \beta z)$ …………….(i)

Where, E_o = peak amplitude

$W = 2\pi f$ rad/sec , f = frequency in hz.
β = propagation factor.
And ,
$\beta = w/v$ ……… (ii)
where, $v = c/n$ ……(iii) [therefore, n = refraction index]
$\beta = wn/c$ ………(iv) [therefore, v = phase velocity]
In free space, $n = n_o = 1$
Therefore, $\beta = \beta_o = w/c$
Equation (iv) becomes,
$\beta = \beta_o n$ ………(v)
Also,
$\lambda = v/f$, the wavelength in any medium.

$\beta = 2\pi/\lambda$
The free space wavelength is ,
i.e λ = ……..= c/f
$\lambda_o/\lambda = c/v = n$ ……(vi)
The wavelength in medium is shorter than in free space because the refractive index is greater than unity.
The power in an optic beam is proportional to the light intensity (which is defined as the square of the electric field) and intensity is proportional to irradiance, the power density (w/m^2).
If a loses energy as if propagates , then equation (i) can not be used and the attenuation becomes important. Therefore the correct equation in this case is,
$E = E_o e^{-\alpha z} \cos(wt-\beta z)$ ………(vii)
Where,
α = attenuation coefficient. It represent losses in fiber, its value determine the rate at which the electric field diminishes a it travels through the lossy medium. Although the decay is exponential, the attenuation coefficient is so small for quality fiber that there is little attenuation even after longer paths.
For a path of length 'L' , the power reduction in decibel is given by,
$dB = 10 \log_{10} e^{(-2\alpha L)}$ ……(viii)
For which the power Change in dB per km will be ,
$dB/km = -8.685\alpha$ ………(xi) Where, α is in km^{-1} .
There exists another useful relationship between the input and the output power loss, which is known as "Beers Law" and is given by:
$P_{out}/p_{in} = 10^{\gamma L/10}$ ………(x)
Where, L = path length.
γ = power change in dB/dm
(= propagation constant = $\alpha + j\beta$)

Dispersion, Pulse Distortion and information rate:

Dispersion:
As we know,
$v = c/n$
For glasses used in optical fibers, the refractive index varies with wavelength. Therefore the wave velocity also varies with wavelength.

"Dispersion" is the name given to the property of the velocity variation with wavelength. Therefore the phenomenon of broadening of light pulses as they propagate down the fiber is know as dispersion.

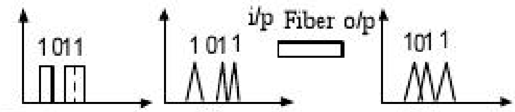

Fig 1(a) (b) (c)

Figure 1(a) and (b) respectively show the digital signal and the corresponding light pulsed, which is i/p to the fiber. Fig 1 (c) shows the dispersion of the light pulses at the other end of the fiber.

The dispersion increases as the length of the fiber is increased eventually becoming indistinguishable at the receiver i/p.

Following table shows the different types of fibers and their dispersive characteristics.

Fiber	BL Product	Dispersion
1. Multimode step index	20Mhz km	Greatest
2. Multimode graded index	1 Ghz km	Moderate
3. Single mode step index	100 Ghz km	Least

Table:1.1

For no overlapping of light pulses at the receiving end of the optical fiber with dispersion, the i/p digital bit rate B_g must satisfy,

$B_g <= 0.5/\tau$

$B_T <= 0.2/\sigma$

Where,

τ = pulse broadening due to dispersion assuming the o/p pulse is gate pulse.

σ = Pulse broadening due to dispersion assuming the o/p pulse takes the Gaussian shape.

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Types of Dispersion:-

1. Material Dispersion:

The material dispersion is caused by the material, the core of the fiber is made up of, and is therefore present in all types of optical fibers.

The optical light sources such as led and laser do not emit just a single frequency but a band of frequencies. Moreover, the reference index of the fiber core is non-liner function of wavelength. It should be noted that the refractive index measured for λ = 585 nm is taken as the standard one , for eg , 1.46 for silica and 1.33 for water. Hence, each frequency or spectral component of the incident light travels with its own velocity. The spectral components therefore reach at the output end of the fiber at different times, which results in the broadening of the light pulses, the dispersion.

For mathematical purposes dispersion is expressed as the rms dispersion (σ_m) or rms pulse broadening, which is defined as

$\sigma_m = \sigma_y LM$ Pico second.

Where,

σ_y = rms spectral width of the i/p pulse in nm.

L = total length of the fiber in km.

M = Material dispersion parameter.

$$= \frac{\lambda}{C}\left|\frac{d^2 n(\lambda)}{d\lambda^2}\right| \text{ ps nm}^{-1}\text{ km}^{-1}$$

It is seen that the rms dispersion can be minimized by

a) Using an optical light source with narrower (coherent) spectral width such as injection Laser rather than Led.
b) Decreasing the length of the fiber.
c) Increasing the operating wavelength.

2. Intermodel or Model or Mode Dispersion:-

When a number of modes in an optical fiber is greater than one, this types of dispersion is occurred. As the different modes that constitute a pulse a multimode fiber travel along the fiber at different group, velocities, the pulse width at the o/p is dependent upon the transmission times of the slowest and the fastest modes. This results in the pulse broadening or dispersion. The magnitude of the intramodel dispersion has already been shown in the table 1.1 before.

The multimode step index fiber exhibit the largest dispersion which gives the largest pulse broadening and the lest bandwidth. The single mode step index fiber has no dispersion and therefore they have the greatest possible bandwidth. The dispersion of multimode graded index fiber falls between these two limits. The factor behind the reduction of dispersion in multimode graded index fiber, comparing with multimode step index fiber is the profile of the refractive index of the fiber core.

Pulse distortion:

When a real source (non zero bandwidth) emits a pulse of light into dispersive glass fiber, the initial pulse consist of a sum of pulses that are identical except for their wavelengths. The several pulses travel at different velocities reaching the end of the fiber at slightly different times. When summed at the output, thus slightly displaced pulses add together, yielding an output i.e lengthen or spread relative to the input signal. This illustrate how dispersion creates pulse distortion. The farther the pulse travels, the greater the spreading and hence results in greater distortion.

Information rate:-

Pulse spreading limits the information capacity of any transmission system. Information rate is the rate of transmission of information per unit time. It is increasing from Mbps to Gbps. And even to Tbps.

The return to zero (Rz) data rate using 3-dB electrical frequency. We have,

$$R_{Rz} = \frac{1}{T} = f_{3-dB}(electrical) = \frac{0.35}{\varnothing\tau}$$

Where, $\varnothing\tau = delay\ period$

Similarly, the non-return-to zero (NRZ) data rate using 3-dB electrical frequency , we have,

$$R_{NRZ} = 2f_{3-dB}(electrical) = \frac{0.7}{\varnothing\tau}$$

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Polarization:- The electric filed of light beam has several directions associated with it. One is the direction of travel and other is the direction of electric field vector itself.

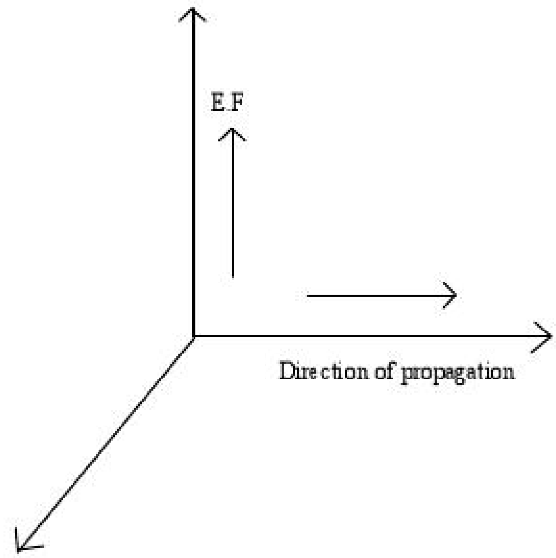


Figure one shows the relationship between the vector E and the direction of travel for a simple plane wave. The wave travels in z direction and EF vector points in x direction. And electric filed that points in just one direction is set to be linearly polarized because it always points along the same straight line.

The actual direction of polarization is determined by the polarization of light source and by any polarization sensitive elements through which the beam passes. It is also possible for two waves to simultaneously travel in z direction, one polarized in x direction and another polarized in y direction. These two waves would be independent to each other because of their orthogonal polarization. The term mode refers to the different ways a wave can travel in a given direction. In a guided structure such as an optic fiber many modes can exist.

Resonant cavities:-

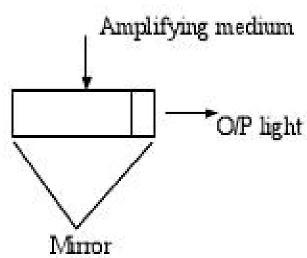


Fig (i): A laser consists of an amplifying medium and two end mirrors.

A laser is very high frequency oscillator. It may correctly be referred to as an optic oscillator. The laser shown in fig(i) consists of a cylindrically shaped medium with mirrors attached to at each end. The medium provides the amplification. Light is amplified in this case. Properties of the medium determine the output frequency and spectral width of the laser. The mirror provides the feedback for light oscillator reflecting the light back and forth through the amplifying medium. Power exits the laser through one of the mirrors which is partially transmitting.

The mirrors form a cavity called "Fabry-perot" resonator within which two wave exists, one moving to the right and one moving to the left resulting in the standing wave pattern.

To produce a stationary standing wave pattern, the cavity must be an integral number of half wave lengths that is

$L = m\lambda/2$ ………….. (i)

Where, λ = wavelength as measured in the material within the cavity

m = a positive integer.

Only wavelength satisfying equation (i) can exists inside the cavity in a steady-state.

We say that a cavity is resonant at wavelengths satisfying equation (i).

These are,

$\lambda = 2L/m$ ………………(ii)

Accordign to equation (ii) cavities are resonant at number of wavelength or frequencies. The resonant frequencies are found as follows:

We know,

$\lambda = v/f$

$v = c/n$

Therefore, $f = mc/(2nL)$ …….(iii)

Where,

n = RI of the material within the cavity.

Reflections at plane boundaries:-

The problem related to the amount of light reflected to the plane boundaries between two dielectrics or media are the important part of study. These problems are particularly critical in the design and analysis of the fiber systems. The reflecting surfaces occur in three situations. These are:

1. Air to glass boundary where light is coupled from a source into a fiber.
2. The interface between the fiber core and its surrounding layer.
3. The two air glass boundaries where there is an air gap between two fibers being connected.

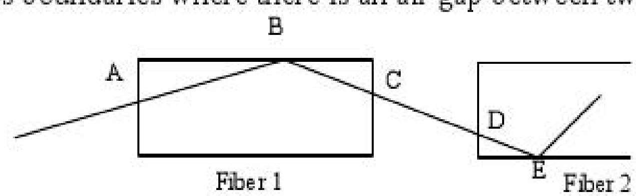
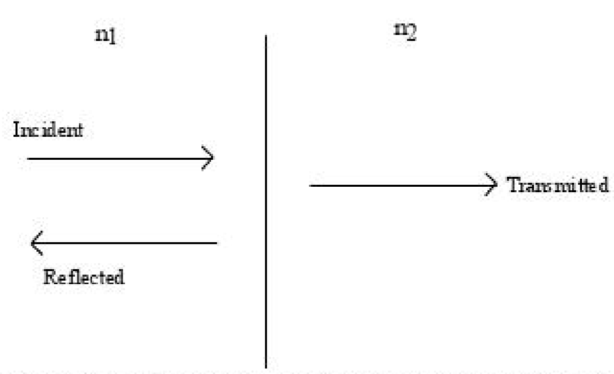


Fig (i) Refractive surfaces in fiber system.



Fig(ii) A wave incident on a plane boundaries between two media.

Light reflected at the input and at the connecter gap because this reflection reduce the power being transmitted. On the other hand the internal reflection at the core boundary should be high to keep the light inside the fiber.

The reflection coefficient ρ is the defined as the ratio of the reflected electric field to the incident electric field. For normal incidents

$$\rho = \frac{n_1 - n_2}{n_1 + n_2}$$

Where,
n_1 = RI in the incident region.
n_2 = RI in the transmitted region.

The "Reflectance R" is the ratio of the reflection beam intensity to the incident beam intensity because the intensity in an optic beam is proportional to the square of its electric field, the reflectance is equal to the square of the reflection coefficient. i.e

$$R = \left(\frac{n_1 - n_2}{n_1 + n_2}\right)^2 \quad \text{.................(ii)}$$

Critical angle reflections:

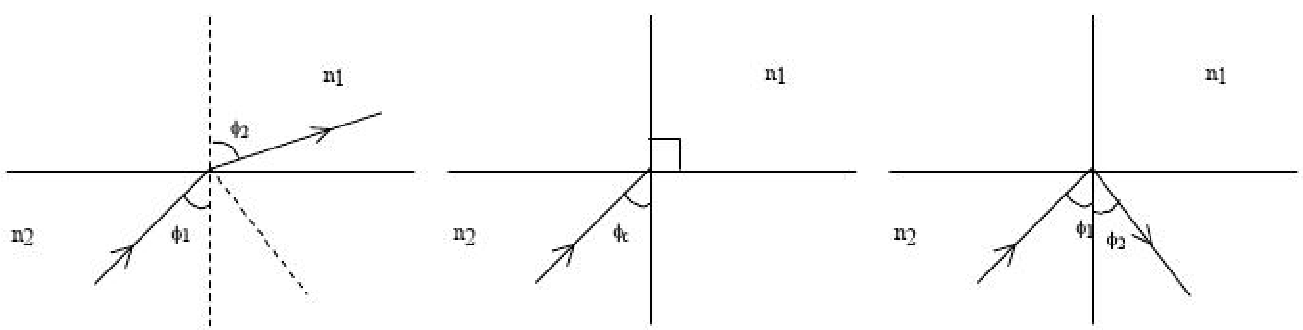


Fig (a) Refraction (b) Critical angle (c) The total internal reflection

The relation between the refrection indexes of the medium and the angle of incident of refraction from the shell's law. i.e

$$n_1 \sin \phi_1 = n_2 \sin \phi_2$$

When angle of refraction is 90, the refracted light propagates along the boundaries separating the media and the corresponding angle of incident is called the critical angle. Nearly all the incident light (99.9%) reflects back to the dense medium when angle of incidence is the greater then the critical angle and this phenomenon is termed as total internal reflection. Therefore, $\sin \phi_c = \frac{n_1}{n_2}$

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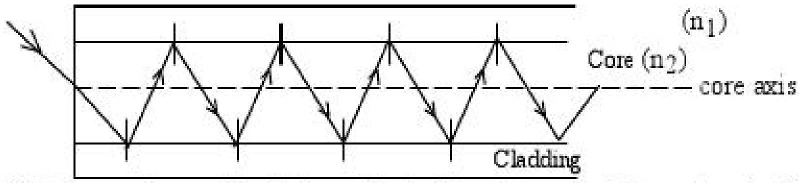


Fig (ii) Propagation of light in optical fiber through internal reflection.

In fig (ii) , the refractive index of the silica (glass) core n_1 is greater than that of the silica cladding n_2 and the light entering into the core form air is incident on the core-cladding interface at an angle greater than critical angle. Hence the light is propagated down the fiber with low loss.

Here, it is assumed that the fiber is perfect one otherwise light would be refracted at the imperfections instead of total reflections resulting in the subsequent loss of light into the cladding. It can therefore ve said that the basis of light propagation in optical fiber is the total internal reflections at the core-cladding interface.

Chapter: 3

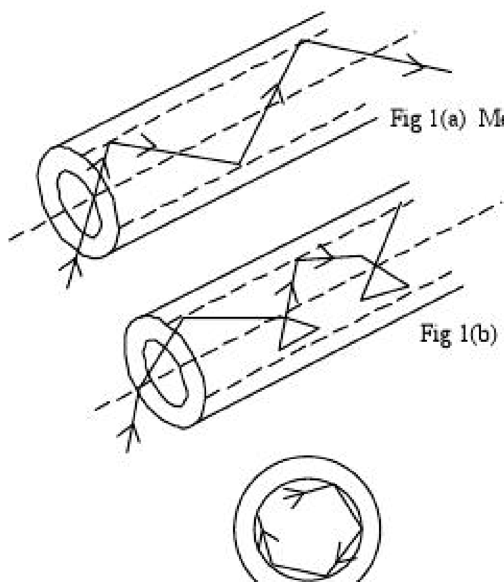


Fig 1(a) Meridonal ray

Fig 1(b) Skew ray

Fig 1(c) Transversive view of skew ray

As shown in figure 1(a) the light ray passes through the axis of fiber as it propagates is called the meridional ray. It is noted that a meridional ray may incident any where on the surface of the core. From symmetric consideration it may be noted that the output angle to the axis will be equal to the input angle for the ray, assuming the ray immerges into a medium of the same refractive index from which it was

input because this type of ray is easy to understand, it is generally use for describing the fundamental transmission properties of the fiber.

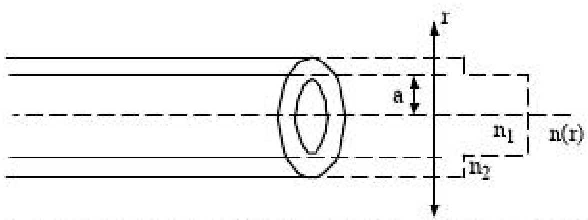
On the other hand the light ray that propagates down the fiber without passing through the axis of the fiber is called the skew ray as shown in fig 1 (b). Thus skew ray propagaties along a helical path. It is not easy to visualize the skew paths in 2D. The transversive view of skew ray into an optical fiber is shown in fig 1(c).

Types of optical fiber:-

On the basis of profile of the refractive index of the fiber, optical fiber an e categorized into two groups:

(1) Step index.
(2) Graded index.

Step index:



An optical fiber with a core of constant refractive index (R.I) n_1 and a cladding of slightly lower refractive index n_2 is know as the step index fiber. A term 'step' is given the because the refractive index profile for this type of fiver makes a step change at the core-cladding interface. All the fibers considered so far are therefore the step index fibers. Fig 1(a) illustrate a step index fiber and equation (1) gives the profile of the R.I.

$$n(r) = \begin{cases} n_1 & r < a \quad (core) \\ n_2 & r \geq a \quad (cladding) \end{cases} \qquad \ldots\ldots\ldots\ldots(i)$$

(ii) Graded index.

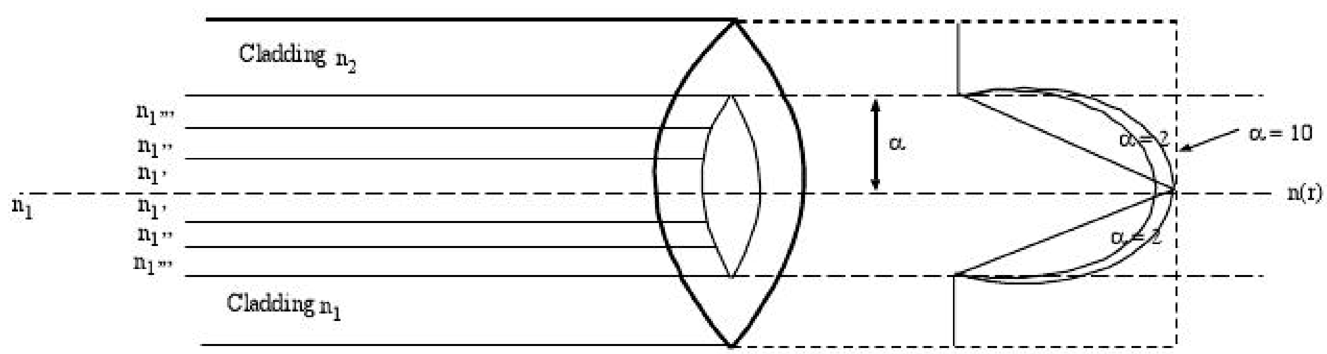


Fig (a) A step index fiber.

The optical fiber whose refractive index is maximum n_1 at the axis of the core, and gradually decreases with the radial distance from the axis to a constant refractive index n_2 in the cladding is known as the graded index fiber. Fig 1(b) shows a sketch of a graded index fiber and equation (2) give the refractive index profile of the fiber. The profile parameter α control the profile i.e the shape of the refractive index of the core of the fiber although an infinite numbers of profile can be obtained with different values of α only step, the parabolic and the triangular profiles are generally considered it is shown in fig 1(b). As shown in fig 1 (b) $\alpha = \infty$ gives step profile $\alpha = 2$ gives parabolic profile and triangular profile when $\alpha = 1$. Form experiments it is found that the distortion of signal propagating along the fiber is least when

$$\alpha = 2 - \frac{12\varnothing}{\phi} \oplus 2$$

Because $\alpha = 2$ produces a parabolic profile. The parabolic graded index fiber is therefore regarded as the best optical fiber when less distortion is sought.

The equation is given as

$$(r) = \begin{cases} n_1\sqrt{1 - 2\varnothing\left(\dfrac{r}{a}\right)^{\alpha}} & r < a \quad (core) \\ = n_2 & r \geq a \quad (cladding) \end{cases}$$

Where,

$\varnothing$= relative refractive indices and is defined as

$$\varnothing = \frac{n_1^2 - n_2^2}{2n_1^2} \oplus \frac{n_1 - n_2}{n_1} \qquad for\ \varnothing << 1$$

α = *profile parameter*

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Attenuation or fiber losses :- Signal attenuation is a major factor in design of any communication system. All receiver requires that their input power be above some minimum level so a transmission losses limit the total length of the path. There are several points in an optic system where losses occur. These are at the channel input coupler, splices and connectors and within the fiber itself. The attenuation within the fiber is less than 5db per km. The attenuation or the losses in optic fiber is categorized as follows:

1. Material absorption loss.
2. Material scattering loss.
3. Bending loss.

Material absorption loss:- Depending the upon the composition and impurities present in the material of which the fiber is made of , some of the light is absorbed within the fiber and is dissipated as heat. This type of loss is termed as material absorption loss and is divided into tow categories:-

1. Intrinsic
2. Extrinsic.

Intrinsic material absorption loss:- This loss is occurred solely due to the composition of materials and is therefore present even in the pure fiber materials when the wavelength of light decreases starting

form around 1.2 μm the material starts to absorb the light . The frequency increases as the wavelength decreases and the photon energy [E = hf] increases accordingly, which results in the excitation of the electrons from low level to high level energy bands. Thus, light is absorbed by the electrons present in the materials.

The peak absorption occurs some where in the ultraviolet region and is therefore this type of absorption is called UV absorption. Because the optical wavelengths use for communication fall between 0.8 to 0.7 μm, therefore the fibers suffer from this type of loss.

On the other hand when the wavelength increase from 1.5 μm, material also starts to absorb light. Because low frequencies (i.e longer wave lengths) , the photon energy is not sufficient to excite the electrons. However, it is enough to vibrate the chemical bonds binding the atoms of the material. Thus light is absorbed by the material. The peak absorption occurs somewhere in the far-infrared region and is therefore this type of absorption is called IR absorption. The fibers also suffers from IR absorption because, the optical wavelength used for communication fall between 0.8 – 1.7 μm.

Extrinsic material absorption loss:- The extrinsic material absorption loss occurs mainly because of absorption of light by metal impurities and hydroxyl (OH) ions mixed with the fiber materials during fabrication. These impurities can be reduce to acceptable level by choosing proper refining techniques such as vapor-phase oxidation. Using the drying agents such as gases chloride may minimize the absorption of light by OH ions.

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As we know a ray used in geometric ray theory is equivalent to electromagnetic wave theory. The rays incident at different angles of incidents at the core cladding interface are treated as different rays therefore it represents a particular mode. When the direction of ray is changed in the course of propagation the newly directed ray may or may not be propagated down the fiber depending upon the angle of incident at core cladding interface.

If the angle of incidence is greater then the critical angle then the ray continues to propagate and it is said that the energy of guided mode is transferred into another guided mode. In this case there is no loss. But if the angle of incident is smaller then the critical angle due to some factors then the ray may not propagate down the fiber which results in loss and it is said that the energy of guided mode is transferred into another mode known as leaky or radiation mode. The transformation of energy from one mode another mode is called coupling and if the loss is occurred due to this coupling (leaky mode coupling). Then it is termed as material scattering loss.

Following are the factors responsible for leaky mode coupling and they may therefore be the causes of material scattering loss.

1. Structural Variation.
2. Compositional Variation.
3. Density Variation.

Bending Loss:- There are two categories of bending loss.

1. Macro bending loss.
2. Micro bending loss.

Macrobendign loss:- The loss that arises from the bents having radii that are larger compare to the fiber diameter. For example, when a cable turns a corner during instillation process, is termed as macrobanding loss.

Microbandign loss:-

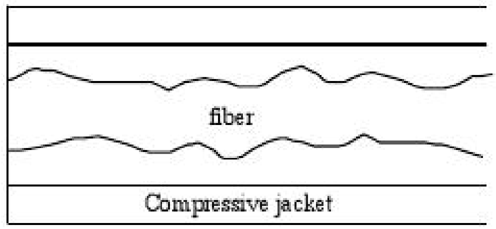

Fig: Microbendig of fiber

The microbends may present in the fiber due to imperfect mechanism involved in the fiber fabrication.

To prevent microbands after fabrication the whole cable may be shielded with compressible jacket as show in figure (1) to offset the external forces which might cause the microbands.

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Acceptance angle:-

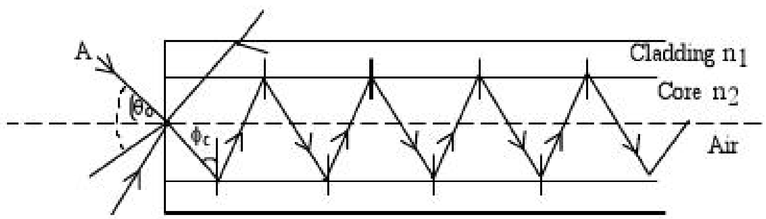

Fig (i)

As shown in figure (i) a meridional ray is incident on air core interface at an angle θ_a and has made the core cladding interface within the fiber at an angle equal to the critical angle ϕ_c . It means that all the light rays within the cone of which the conical half angle is θ_a, will incident on the core cladding interface within the fiber at an angle greater then the critical angle and propagate along the fiber by total internal reflection.

The angle θ_a which is the maximum angle to the axis at which light may enter the fiber inorder to propagate is called the acceptance angle for the fiber. For comparison a meridional ray 'B' is incident at an angle greater then θ_a and it is refracted into the cladding and is eventually lost by radiation.

Numerical aperture (NA):-

Numerical aperture is an important parameter that shows the light collecting ability of a fiber and establishes the relation between the acceptance angle and the refractive indexes of the three media namely core, cladding and air. The numerical aperture for meridional ray and skew rays are different but here we are only dealing about NA for meridional rays.

The NA For Meridional rays:-

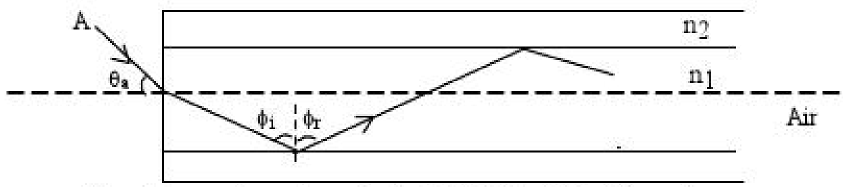

Fig: Parameters to calculate NA for Meridional rays.

Referring to fig (ii) , and using Snell's law.

$n_o \sin\theta_o = n_1 \sin\theta_1 = n_1 \cos\phi = n_1\sqrt{1-\sin^2\phi}$

When the limiting case is considered, i.e when incietn angle θ_o is equal to the acceptance angle θ_a i.e $\theta_0 = \theta_a$ then the angle ø equals the critical angle ϕ_c at the core-cladding interface.

We have therefore,

$n_o \sin\theta_o = n_1 \sin\theta_1 = n_1 \cos\phi = n_1\sqrt{1-\sin^2\phi_c}$ ....(ii)

But

We know,

$\sin\phi_c = n_2/n_1$ ....(iii)

Therefore equation (ii) can be written ad,

$n_o \sin\theta_a = n_1\sqrt{1-\left(\frac{n_2}{n_1}\right)^2} = n_1\sqrt{\frac{n_1^2-n_2^2}{n_1^2}}$

$n_o \sin\theta_a = \sqrt{n_1^2-n_2^2}$ ....(iv)

We consider that the refractive index for air is 1 i.e $n_o = 1$.

$\therefore NA = \sin\theta_a = \sqrt{n_1^2+n_2^2}$ ....(v)

Thus, it is noted that NA establishes a relation between the acceptance angle and the refractive indices. More importantly, the NA show a the light collecting ability of a fiber because it is directly related to the acceptance angle .

Moreover there is a parameter called relative refractive index difference '∅' between the core and the cladding and is defined as,

$\varnothing = \frac{n_1^2-n_2^2}{2n_1^2} \oplus \frac{n_1-n_2}{n_1}$ $for\ \varnothing << 1$

Thus ,

NA can also be written in terms of '∅' as,

$NA = n_1\sqrt{2\varnothing}$ ....(v)

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Pulse distortion and information rate in optical fiber:-

Fiber links are limited in path by attenuation and pulse distortion. In some application the signal reaching the receiver is too weak for clear reception although the received signal shape is not

objectionable. When attenuation is a measure problem the system is power limited. There are also losses that are due to the fiber itself. We need to look at the added losses occurring at the source coupler and at splices and connectors. For some links the power is sufficient but the distorted signal shape cannot get or recover the correct reconstruction of the transmitted message. Such system are called band width limited.

Signal are distorted in step index (SI) fiber by material and web guide disposition and by multimode pulse spreading . The amount of multimode pulse spreading can be written as,

$$\varnothing(\tau / L) = \frac{n_1}{c}\varnothing = \frac{NA^2}{2cn_1}$$

Where, n_1 and n_2 are nearly equal. By using the values $n_1 = 1.48$ and $n_2 = 1.46$, typically of glass fibers, we find,

$\varnothing(\tau / L) =$ 67 ns/km. This is rather high number. In fact most SI glass fibers have measured pulse spreads a bit lower, around 10-50 ns/km.

Graded index (GRIN) fibers produced much less multimode distortion then SI fibers. We can explain this by considering ray trajectories and velocities in GRIN fibers. Axial rays travel the shortest root. Rays that cross the fibers axis at large angles travels farther but they speedup when propagating through regions away form the axis, where the refractive index is lower since $v = c/n$. During the time spent away from the axis , non axial rays catch up with the axial rays. This process minimize the multimode pulse spreading . Typical multimode GRIN fibers have pulse spreads of just a few nanoseconds per km or less (Generally 0.45 ns/km for $n_1 = 1.48$ and $n_2 = 1.46$). Which is much smaller then the pulse spreads in SI fibers.

An approximation expression for the model pulse spread in GRIN fibers is $\varnothing(\tau / L) = \frac{n_1\varnothing^2}{2c}$

Construction of optical fiber:-

As many other process the outside vapor phase oxidation (OVPO) used to prepare both the step index of Graded index fiber.

The $SiCl_4$ in the gaseous state are mixed with oxygen to obtain pure SiO_2 and GeO_2 as given by the following reactions.

$SiCl_4$ + $2H_2O$ $\rightarrow$ SiO_2 + $4HCl$
(vapour) (gas) (solid) (gas)
$GeCl_4$ + O_2 $\rightarrow$ GeO_2 + $2Cl_2$
(vapour) (gas) (solid) (gas)

The mixture of SiO_2 and GeO_2 is then passed through a burner so that layer of this mixture is deposited on a cool rotating mandrel as shown in figure (i). The burner is moved back and forth over the length of the mandrel to deposit approximately 200 layers of the mixture.

The amount of GeO_2 is not changed until the core cladding interface is reached to prepare a step index fiber where as it is gradually changed at the composition of each traverse of the burner for preparing a GRIN fiber. In this process SiO_2 is the base material of GeO_2 is called the dopant.

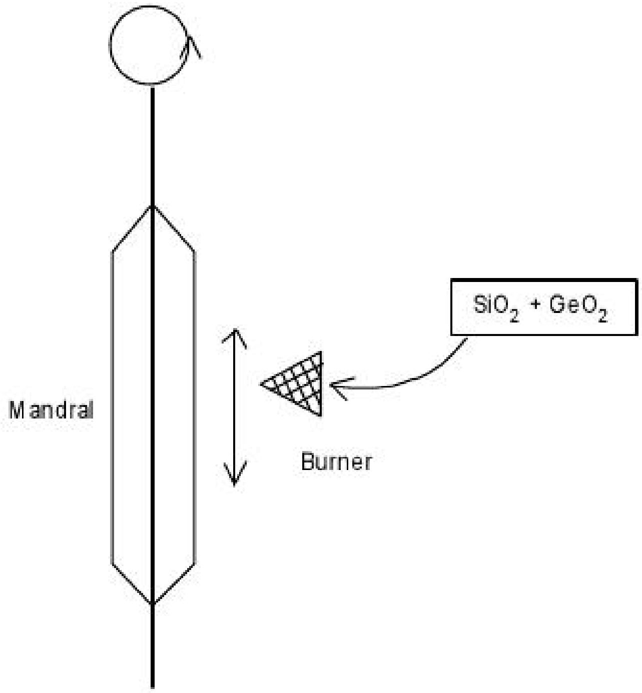

Fig (i)

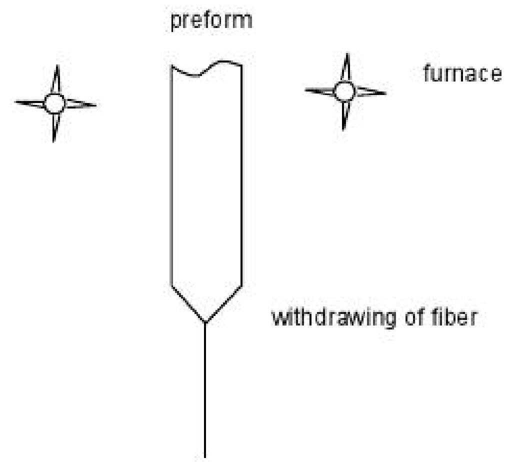

Fig (ii)

The compound such as P_2O_5 and F can also be used as dopainds. After depositing the required number of layers, the mandrel is removed and the central hole is collapse. The resulted shape of the mixture is called the perform. A fiber in fig (ii). It is possible to draw a fiber of length around 10 km with 120 micrometer core diameter. The mixture form which the fiber is prepared is usually devoted by a single symbol such as GeO_2-SiO_2 and is read as Silica glass dopped with GeO_2.

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The amount of protection of a fiber varies from one application to another. In a lab setting a fiber protected by a thin protective (jacket coating) might be quite serviceable while transoceanic fiber would need considerable protection during transportation installation and operation. A variety of cable designs have been implemented to meet the requirement of different fiber applications.

Cabling should improve the mechanical characteristics of a fiber without causing a detoriation of its optical properties. Cabling can cause microbends in the fiber increasing its attenuation. Microbends can also occur when the finished cables is stressed by the movement of any sort (e.g When cable is coiled on a ring). Cables are designed to minimize microbends during constructions and limit their occurrence later.

The types of strengthening and protection needed are as follows:

- Tensile strength .
- Crush resistance.
- Protection from excess bending.
- Vibration isolation.
- Moisture and chemical protection.

- Aberation protection.

In addition to being strong and chemical resistance, good fiber cables are light, small, flexible, flame redardant, rodent resistance and temperature insensitive.

Several general structure forms that produce adequate cables have evolved. Among variations, some of importance are as follows:

1. Single fiber cables and Multifiber cables.
2. Tightly packed fibers (referred as tight buffer) and lossely held fibers (called loose-tube buffer).
3. Centralized strengthing members and externally located strengthing members.
4. Dielectric strenghting members and metallic strengthing members.
5. Circular geometrics and ribbon geometries.

(Note: Chapter 4 and 5 covers from manual.)

Chapter:- 4

Light sources:-

Properties:

1. Compatible size.
2. Tracking of signal.
3. Narrow spectral width.
4. Direction modulation must range from AF to GHz range.
5. Couple sufficient optical power.
6. Most provide stable output.
7. Cheap and reliable.

Optical sources are of two types:-

1. LED (light emitting Diode)
2. LASER (Light Amplification by stimulated emission)

Spontaneous and stimulated emission:-

Optical source parameter:-

(1) Radiance (Brightness):-

$$\text{Radiance} = \frac{Optical\ \ power\ \ output}{area\ (Solid\ \ angle)} \quad (\text{w/m}^2\text{sr}).$$

(2) Lambertian power pattern:

Figure:

(3) Internal quantum efficiency.

$$\eta_{int} = \frac{r_r}{r_r + r_{nr}} = \frac{r_r}{rt}$$

r_r = radiative combination rate.
r_{nr} = non radiative combination rate.
r_t = total combination rate.

General principle of LED:-

- Based on spontaneous emission.
- Since it is random process, there may be random phase of em waves.
- Due to which this type of source has low radiance.
- It is also a PN junction diode and works in forward bias.
- Si or Ge → Normal diode.
- GaAs, GaP, GaAsP, GaInP, AlGaAs, InGaAs and InGaAsP. → LED

Types of LED:

There are 4 types of LED:-

(1) Planner LED
(2) Dome LED.
(3) Surface emitter LED. (SLED).
(4) Edge emitter LED (ELED).

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Planner LED:

- P-type GaAs diffuse with n-type GaAs substrate, forms a junction and works as a planer LED.
- Pattern is lambetian pattern.
- But radiance is low.
- Due to large surface area and reflections within the diode.
- So not use in OF
- Used as TV indicator.

Dome LED:

On the basis of junction LED:

1. Homojunction LED
   - If same type of semiconductor material is used.
2. Heterojunction LED
   - If different type of semiconductor material are used there by generating different junction.

SLED (surface emitter LED):

- used in OFC.
- Figure:

Edge emitter LED:

- Light is emitted through the edge.

Optical source characteristics:
LED characteristics:
1. optical output power.
2. Temperature dependent.
3. Spectral width(line width).
4. Electrical and optical bandwidths.
5. Transient time.

Optical output power:

Figure:

Temperature dependence:
Figure:

Spectral line width:
LED - 0.8 to 0.9 micro meter wavelength.
(Spectral line width – between 25 to 40 nm).
- 1.1 to 1.7 micro meter wavelength. Then spectral line width – between 50 to 160.

Electrical and optical bandwidth:

Transient time: Time taken to reach the half of the maximum power.

$$t_{\frac{1}{2}} = \frac{c_j}{\beta I_p} l_n \frac{I_p}{I_s} + \tau l_n 2$$

$$\beta = \frac{q}{2k_B\tau}$$

For chapter V read the following chapter:-
Nose: topic 11.1 (page 275), 11.2 SNR and BER,

Chapter: 6
Optical Devices (page no 190).
Topic: 8.3, 8.4
Page no: 232
Topic: 9.4 optical switches.
9.5 Fiber optical isolators.
9.6 Wavelength division .

Optical fiber communication and application - by S.C Gupta.
Page: - 342 optical ADD/DROP multiplexer.

Example: 04: A silica optical fiber with a core dia (2a) has a core refractive index of 1.50 and a cladding refractive index of 1.47. Calculate NA of the fiber and the critical angle of core cladding interface for the silica fiber.

Example: 05 Two fibers are joined together after polishing whose core refractive index is 1.5 and there is little air gap between the fiver end faces. Calculate the loss of light signal in dB at the joint area.

Solution:

$n_1 = 1.5$

$n_2 = 1$

$$\therefore R = \left(\frac{n_1 - n}{n_1 + n}\right)^2 = \left(\frac{1.5-1}{1.5+1}\right)^2$$

$$\therefore Loss\ in\ dB = -10\log_{10}\ (1-R) =$$

2008(R):

EX:06. A graded index fiber with a parabolic index profile supports the propagtiaon of 742 guided modes. The fiber has a NA in air of 0.3 and a core diameter of 70 micro meter. Determine the λ of light propagation in the fiber. Further estimate the maximum diameter of the fiber which gives single mode operation at some wavelength.

Ex 07: For a planer LED device fabricated from GaAs which has a refractive index of 3.6. Calculate the conversion efficiency if electrical power is 5v and an optical output is 50 micro watt. Where as device current is 10 micro ampere.

Solution:

The conversion efficiency is

$$\eta_c = \frac{optical\ power}{Input\ poer} = \frac{50\,\alpha m}{5 \times 10 \times 10^{-6}}$$

$$\therefore \eta_c(\%) = \ \ldots\ldots\ldots\ldots\ldots$$

Ex 08: A photodiode has a quantum efficiency of 70% when the photon of energy 2.2×10^{-19} J are incident on it. Calculate the wavelength of operation of device along with its responsivity when the photocurrent generated in the photodiode is 2 αA. Also find out the amount of incident power for the above current.

Solution:

$$E = 2.2\times10^{-19}\ J$$

$$\eta = 70\%$$

We know that ,

$$\lambda = \frac{hc}{E} = \frac{6.626 \times 10^{-34} \times 3 \times 10^{8}}{2.2 \times 10^{-19}} = 0.9 \propto m$$

$$\therefore R = \frac{\eta e \lambda}{nc} = 0.51 AW^{-1}$$

Also,

$$R = \frac{I_p}{p_i} =$$

$$\Rightarrow p_i = \frac{I_p}{R} = \frac{2 \times 10^{-6}}{0.51} = 3.92 \propto w$$